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BY

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GREEN MANURE CROPS IN SOUTHERN CALIFORNIA*

By W. M. Mertz

INTRODUCTION

In a comparison of factors governing agricultural practice in humid climates and in a semi-arid section as southern California, the two most striking differences are apparent in connection with the moisture content and the organic content of the soil. The development of successful agriculture under this semi-arid condition depends in large measure upon supplying the deficiencies in water and organic material. In the case of water, the question resolves itself into two factors: first, is there an available source of water; and if so, can it be put upon the land at a cost which the returns from the crop will warrant? The question of maintaining the supply of organic material in the soil after the water has once been applied to the land is the next most vital problem. Agricultural soils of semi-arid regions are notably deficient in organic matter. One of the chief concerns of the farmer is to obtain soil organic matter cheaply in order to maintain a supply in the soil sufficient for the needs of the crops to be grown. Two methods present themselves: the first, that of incorporating into the soil various animal manures and waste products; the second, that of plowing under green manures grown in rotation with field crops, or between the rows of orchard trees.

Where the supply of organic matter is low, there is usually a corresponding lack of nitrogen. Thus the two problems of increasing the organic matter and increasing the nitrogen content, are closely bound together. The use of animal manures tends to accomplish both of these objects. Complications arise, however, in the way of expense, for only a very small percentage of our farmers are stock-raisers, and many orchardists do not even keep their own work teams. It thus becomes necessary for the orchardist to buy a very large proportion of the animal manures used. Under the increasing demand, these manures have advanced in price and are available only in limited quantities.

[1] Paper no. 46, University of California, Citrus Experiment Station, Riverside, California.

The question naturally arises, cannot legumes be found that would be suitable for green manuring, the use of which would maintain both the organic and nitrogen contents of the soil? For several years attempts were made to use various legumes as green-manure crops, especially in citrus orchards. After quite extensive trials, growers in general adopted two species, spring vetch (*Vicia sativa*), and Canada peas (*Pisum arvense*). This practice was based largely upon the fact that the seed of these two plants was obtainable in large quantities at reasonable prices and that both crops gave heavy yields of organic material. Of late years, these legumes have not been giving entire satisfaction and are going out of use in large measure. This state of affairs emphasized the necessity for finding other legumes better adapted to the conditions. Since a tendency was shown to revert to cereals as green-manure crops, it seemed advisable to attempt to verify under local conditions the findings of eastern writers on the relative values of legumes and non-legumes.

This publication has three objects:

1. To give the results of a six-year experiment on the relative effects of different green-manure crops, including both legumes and non-legumes.

2. To bring up to date the results of a ten-year experiment with green-manure crops in a citrus orchard.

3. To bring together the experimental and observational data on the subject of green manuring in general.

A. WINTER GREEN-MANURE CROPS IN ANNUAL ROTATIONS WITH CERTAIN FIELD CROPS

OBJECT OF EXPERIMENT

The objects of this experiment were:

1. To determine the relative value of a number of legumes as measured by their ability to produce consistently heavy yields under fall and winter conditions.

2. To determine the relative value of a number of different legumes and non-legumes as green-manure crops, when measured by their effect on the yields of annual field crops following them.

3. To determine the fertilizing value of legume green manures in comparison with commercial forms of nitrogen when added in conjunction with cereal green manures.

Fig. 1.—*A*, *Vicia atropurpurea* (purple vetch); *B*, single flower of *Vicia atropurpurea*; *C*, *Melilotus indica*; *D*, pod of *Vicia sativa*; *E*, *Vicia sativa* (common vetch); F, view looking into a single flower of *Vicia sativa*.

HISTORY

The experiment herein outlined was started at Riverside by the University of California, Citrus Experiment Station. The preliminary work was under the direction of J. H. Norton. Since 1912, the work has been under the supervision of the author. A tract of land on the Rubidoux Experimental Farm at Riverside, California, was divided into tenth-acre plots, and so arranged that each plot was irrigated separately. These were numbered consecutively from west to east. The soil is a light Sierra sandy loam, tending to become somewhat heavier on the east side of the block.

OUTLINE OF EXPERIMENT

In the execution of this experiment, the tract of land used was divided into seventeen plots, each 20 feet wide by 218 feet long, containing approximately one-tenth of an acre. These were numbered consecutively 1 to 17. The plan of the experiment was to grow different green-manure crops on these plots during the winter months. During the summer following, certain indicator crops, such as corn and potatoes, were to be grown in solid blocks crossing the plots and serve by their growth and yield to demonstrate the comparative value of the different treatments applied to the plots.

The plots indicated by the odd numbers have all had some variety of legume grown on them each winter and turned under as a green manure in the spring. The plots of even numbers have had non-leguminous plants grown and turned under. Certain of these non-legume plots were fertilized with commercial nitrogenous materials during the growth of the indicator crop, thus furnishing some means of comparing the value of nitrogen from the leguminous manure crop with known quantities of nitrogen from commercial fertilizer.

The treatment given each plot was as follows:

Plot 1.—Common vetch (*Vicia sativa*). (Fig. 1.)

Plot 3.—Bur clover (*Medicago hispida denticulata*).

Plot 5.—Crimson clover (*Trifolium incarnatum*), during the first three years of experiment. This crop failed to germinate in every case, and in the winters of 1913–1914 and 1914–1915, the plot was sown to purple vetch (*Vicia atropurpurea*). (Figs. 1 and 3.)

Plot 7.—Wild lupine for the first year. This failed to germinate, and beginning with the winter of 1910–1911, the plot has had bitter vetch (*Vicia ervilia*) grown upon it.

Plot 9.—Canada field peas (*Pisum arvense*). (Fig. 3.)

Plot 11.—Tangier peas (*Lathyrus tingitanus*).

Plot 13.—Soja beans for first year. This proved to be too tender for a winter crop, and beginning with the winter of 1910–1911, bitter clover (*Melilotus indica*) has been grown upon this plot. (Figs. 1 and 2.)

Plot 15.—Fenugreek (*Trigonella Foenum-Graecum*).

Plot 17.—Lentils (*Lens esculenta*).

The plots with even numbers have had growing upon them each year the same non-legume. Different crops have been used during the several years. In the winter 1909–1910, weeds were allowed to grow on these plots. During the winters of 1910–1911, 1911–1912, and 1914–1915, barley was grown, in 1912–1913, alfilaria (*Erodium cicutarium*), and during the winter of 1913–1914, rye was used.

CULTURE OF WINTER CROPS GROWN AS GREEN MANURES

The soil was disked or plowed early in September of each year. The clover seed was then sown broadcast and harrowed into the soil. The other larger-seeded crops were sown broadcast and harrowed into the soil for the crops of 1910, 1911, 1912, and 1913. During the other seasons a grain drill was used. Better stands usually followed drilling than broadcasting. As soon after sowing as possible, the land was furrowed out for irrigation. From three to five acre-inches of water was applied at intervals of three to six weeks.

In the spring, the crop from typical areas (20×20 feet) in each plot, was cut and weighed to determine the tonnage of green tops at time of plowing. The results of these weighings are shown in table II where the average tonnage produced by each green-manure crop is given. The samples were cut at the surface of the soil and immediately weighed. The figures on tonnage represent the entire top growth produced on the plots, as no attempt was made to eliminate the weeds during the growth of the crop or at the time of weighing. The tonnages produced are more uniform than would have been the case had the top growth of the planted crop been weighed alone. Thus the tonnages given may be compared with those obtained under ordinary field conditions where a certain percentage of the crop is made up of the common weeds.

In late February or early March, a dressing of raw rock phosphate, 540 pounds per acre, and sulphate of potash, 324 pounds per acre, was uniformly applied over all plots. Following this operation, the

plots were plowed to a depth of nine to ten inches. This was usually done with a large eighteen-inch moldboard plow equipped with fourteen-inch rolling cutter and heavy weed-chain, which completely buried all of the tops.

CULTURE OF SUMMER CROPS GROWN AS INDICATORS OF RELATIVE VALUE OF VARIOUS GREEN MANURES

Following the preparation of a good seed-bed, summer field crops were planted. This was usually done during the months of March or April, depending upon variety and season. During the growth of these summer indicator crops, applications of nitrogen were made to the non-legume plots, nos. 2, 6, 10, and 14.

The amounts and sources of the nitrogen added are shown in Table I:

TABLE 1

NITROGENOUS FERTILIZERS APPLIED TO PLOTS 2, 6, 10, AND 14, IN POUNDS PER ACRE

Plot	Treatment	Nitrate of soda during seasons of 1910, 1911, 1912, and 1913, pounds	Dried blood during seasons of 1914 and 1915, pounds
2	Non-legume green manure and 123 lbs. N per acre	810	900
6	Non-legume green manure and 41 lbs. N per acre	270	300
10	Non-legume green manure and 163 lbs. N per acre	1080	1200
14	Non-legume green manure and 82 lbs. N per acre	540	600

The nitrate of soda was divided into two or three applications made during the early development of the indicator crops. With the dried blood the entire amount was applied after plowing under the green-manure crops and then disked into the soil before the planting of the summer crops. During the summers of 1910 and 1911, cabbage, corn, and sugar beets were grown as summer indicator crops. With each of these three crops the yields were heavy, and those of the check plots were reasonably uniform. Potatoes and corn served as the indicator crops for the season of 1912. Potatoes, corn, and sorghum were used as the indicator crop in 1913. The sorghum followed the potatoes which were harvested early in June. During 1914, corn was used as the summer indicator crop. The results of this year were satisfactory, although the wireworm caused considerable irregularity in the stand. Sudan grass was grown as the indicator crop for 1915. This crop was sown broadcast and two cuttings of hay removed.

Fig. 2.—A, Melilotus clover plant (1/10 natural size). Note tendency to root deeply. Its upright branching habit is shown in this cut. B, Partial root system of melilotus clover plant (½ natural size). Note large taproot and presence of small nodules on the fibers.

RESULTS OF EXPERIMENTS

YIELDS OF DIFFERENT GREEN-MANURE CROPS

Assuming that organic matter is of prime importance in maintaining fertility in California soils, the value of green-manure crops must be judged in part by their ability to produce heavy tonnages under average winter conditions. Table II gives the average yield of green matter produced by the different green manures at the time they were turned under. The tonnages vary from 7.5 to 20 tons, with most of the crops averaging about 12 tons of green tops per acre. The very heavy yield of purple vetch is, however, the average of only two years as compared with a five-year average of the other crops.

TABLE II

AVERAGE TONNAGE AND COMPOSITION OF GREEN MATTER TURNED UNDER ON EACH LOT

Plot	Green manure crop	Average tonnage of green manures on acre basis	No. of analysis	Percentage of water	Per cent nitrogen in green weight	Pounds of nitrogen per ton green tops	Pounds nitrogen per acre
1	Common vetch	12.0	25	82	.538	10.8	129.6
2	Non-legume*	10.9	4	82	.281	5.6	61.0
3	Bur clover	12.7	21	84	.637	12.7	161.3
4	Non-legume*	9.0	4	82	.281	5.6	50.4
5	Purple vetch†	20.0	5	81	.569	11.4	228.0
6	Non-legume*	9.7	4	82	.281	5.6	54.3
7	Vetch	12.8	4	82	.518	10.4	133.1
8	Non-legume*	9.2	4	82	.281	5.6	51.5
9	Canada peas	7.5	18	80	.633	12.7	95.2
10	Non-legume*	11.0	4	82	.281	5.6	61.6
11	Tangier peas	13.7	5	86	.494	9.9	135.6
12	Non-legume*	8.7	4	82	.281	5.6	48.7
13	Melilotus indica	13.7	9	80	.556	11.1	152.0
14	Non-legume*	10.5	4	82	.281	5.6	58.8
15	Fenugreek	12.3	12	82	.557	11.1	136.5
16	Non-legume*	8.9	4	82	.281	5.6	49.8
17	Lentils	12.1	7	75	.650	13.0	157.3
Average of nine legume plots		13.0	11	81	.572	11.4	148.2
Average of eight non-legume plots		9.7	4	82	.281	5.6	54.3

* Non-legume tonnages and compositions are averages of barley, rye, and alfilaria.

† Purple vetch was grown but two years.

‡ The author is indebted to Professor J. H. Norton and Messrs. H. D. Young and E. E. Thomas for most of the analyses from which the averages contained in this table were computed.

Fig. 3.—A, partial root systems of purple vetch (½ natural size). Note the number of lateral fibers and absence of any well defined taproot. B, Partial root system of Canada pea (½ natural size). Note large size of nodules characteristic of this plant. This is not, however, an indication that more nitrogen is being taken from the air.

Although no records were made of the percentage of weeds present in the various green manure crops, there were very noticeable differences in this regard. The common vetch was always badly infested with the western pigweed (*Chenopodium murale*). To a lesser extent this was also true of *Vicia ervilia* and fenugreek. During the last three years of the experiment, the stand of Tangier peas was poor and thus enabled weeds to get a foothold on Plot II.

The common vetch was seriously affected with the green pea aphis during the winters of 1911–12 and 1912–13. Bur clover was slow in its early development and was thus unable to smother out the weeds as satisfactorily as certain others. The fenugreek gave poor results during several winters from causes not understood. It is naturally a smaller growing plant than the others and seemed less able to withstand adverse temperature and moisture conditions. Lentils gave good yields of green tops during the first two seasons, but later suffered from a root disease. Canada field peas gave good yields and pure stands during the first two years, but later the yields were markedly reduced by aphis injury, poor germination and frost. The newly introduced bitter vetch (*Vicia ervilia*) gave better stands than the common variety, but was not sufficiently vigorous to smother the weeds. Purple vetch,[2] like the foregoing variety, is a recent introduction of the United States Department of Agriculture. This variety gave very heavy yields for the two years tested and seemed able entirely to smother weeds. *Melilotus indica* gave more uniform results as to stand than any other variety tested. Nothing seemed to affect it materially, its most serious disadvantage being its slow early development. It was more easily handled in the spring because of its upright habit and was not seriously damaged by the tramping necessary in orchard heating. Temperatures as low as 16° F., although checking its development, did not injure it as was the case with all other varieties except bur clover.

COMPOSITION OF DIFFERENT GREEN-MANURE CROPS

Table II also gives the average nitrogen content of the crops used as green manures in the experiments which includes several of those most commonly used in southern California. The nitrogen content is based on the green weight of the tops at time of plowing.

[2] The author is especially indebted to Professor Roland McKee, Assistant Agrostologist, U. S. D. A., Bureau of Plant Industry, for his active cooperation in furnishing seed of the Tangier pea, purple vetch, and bitter vetch (*V. ervilia*).

The percentage of nitrogen shown in these analyses indicates that with the legumes a considerable portion of the nitrogen they contain must have been derived from the air, since on the same soil, from two to three times as much nitrogen had gone into the tissues of the legumes, as was the case with the non-legumes. This is further borne out by the analyses of the soils of the various plots. The soil was sampled during January, 1914, while the crops were still growing, thus representing the soil's condition as to nitrogen before that contained in the green crop had been returned to it. The average of

Fig. 4.—Showing yields of corn on plots 10, 12, and 13, for the season 1912: 10, barley plowed under and 108 pounds of nitrate of soda added; 12, barley plowed under—no fertilizer; 13, bitter clover (*Melilotus indica*) plowed under—no fertilizer.

fifteen analyses of the legume plots showed a total nitrogen content of .032 per cent, while the average of eight analyses of the non-legume plots shows a content of .027 per cent nitrogen. Since these samples were taken to a depth of two feet, this difference of .005 per cent of nitrogen represented an apparent gain of 400 pounds nitrogen per acre.

Table III gives the average yields of the six indicator crops for each plot on the acre basis. The figures in italics are the yields of the unfertilized non-legume plots where the green manure crop was rye or barley. The yield of the four unfertilized non-legume plots

are uniformly low when compared with those of the plots where legumes had been turned under or where nitrogenous fertilizer had been applied to the non-legume plots. It is significant, however, that the low yields on the unfertilized non-legume plots are practically equal to the state average for these crops.

Table IV gives the percentage of increase in yield of the legume plots, and those receiving nitrogen additions over those where non-legume green manures were used alone. These figures were obtained by comparing the yield of each plot where legumes had been turned

Fig. 5.—Showing yields of corn on plots 1, 4, and 5 for the season of 1912: 1, common vetch plowed under—no fertilizer; 4, barley plowed under—no fertilizer; 5, purple vetch plowed under—no fertilizer.

under, with the yield of the adjacent unfertilized non-legume plot. The increases noted on plots 2, 6, 10, and 14, were obtained by comparing these plots fertilized with nitrogen with the average of the yields of the two nearest unfertilized non-legume plots. Thus Plot 13, where a green-manure crop of *Melilotus indica* had been turned under, was compared in yield with that of the unfertilized non-legume Plot 12. The yield of Plot 10, which had non-legumes turned under and nitrogenous fertilizer applied, was compared with the average of the yields on the unfertilized non-legume plots 8 and 12.

Very marked effects are noted in the great majority of the cases where a commercial nitrogenous fertilizer was used in addition to rye or barley green manure (fig. 4). With the exception of Plot 2, the amount of increase was roughly in proportion to the amount of nitrogen added. Where 41 pounds of nitrogen was added, the average increase was 12.8 per cent; with 82 pounds, 30 per cent increase; and with 163 pounds, 51 per cent increase.

Striking results are, however, noticed on plots where legumes were used as green manures (fig. 5).

TABLE III

YIELDS FOLLOWING VARIOUS SOIL TREATMENTS IN POUNDS PER ACRE

Plot	Treatment	Shelled corn, 5-yr. aver.	Potatoes, 2-yr. aver.	Cabbage,† 2-yr. aver.	Beets, 2-yr. aver.	Sorghum hay, 1913	Sudan grass hay,‡ 1915
1	Common vetch	2,125	10 243	....	30,640	8,363	....
2	Non-legume + 123 lbs. N	2,046	11,504	....	32,106	11,580	16 245
3	Bur clover	2,135	13,671	11,689	34,748	9,489	14,079
4	Non-legume (check)	1,693	9,275	10,639	26,878	7,505	13 395
5*	Purple vetch	3 091	....	....	....	....	17,470
6	Non-legume + 41 lbs. N	1,929	9 982	11,714	25,048	9,114	16,615
7	Vicia ervilia	2,293	13,874	18,139	36,888	9,516	16,957
8	Non-legume (check)	1,550	9,942	10 314	21,476	8,792	13,908
9	Canada peas	2 235	14,600	15,571	35,270	11,231	15,789
10	Non-legume + 163 lbs. N	2,462	13,103	15,108	34,424	12 733	20 320
11	Tangier peas	2,523	13,607	16,405	41,192	12,250	17,841
12	Non-legume (check)	1.617	9 823	7,678	24,687	7,881	15,988
13	Melilotus indica	2,754	15,115	19 835	47 300	11,607	19,038
14	Non-legume + 82 lbs. N	2,395	12,256	13,024	31,388	11,770	20,206
15	Fenugreek	2,652	15,322	13,208	33,567	10,374	19,038
16	Non-legume (check)	1 973	9 887	11,865	25,362	9 971	16 359
17	Lentils	2 569	12,268	12,793	38,931	12,224	16,800
Aver. of legume plots		2,486	13,588	15,377	37,317	10,632	17,126
Aver. of non-legume plots fertilized with an average of 102 lbs. nitrogen		2 208	11,711	13,282	30,741	11,299	18,346
Aver. of unfertilized non-legume plots		1,708	9,732	10,124	24,601	8,537	14,912

* Purple vetch was grown as green-manure crop during the years 1914 and 1915 only.

† Cabbage on Plots 1 and 2 was so seriously injured by rabbits that the yields of these plots cannot be taken into consideration in getting the average.

‡ Sudan grass was such a poor stand on Plot 1 that it was thrown out of the experiment.

TABLE IV

PERCENTAGES OF INCREASE IN YIELD OF INDICATOR CROPS BASED ON A COMPARISON OF LEGUME, AND NITROGEN FERTILIZED NON-LEGUME PLOTS WITH THE UNFERTILIZED NON-LEGUME PLOTS AS CHECKS

Plot	Treatment	Corn, 5-yr. aver. per cent	Potatoes, 2-yr. aver. per cent	Cabbage, 2-yr. aver. per cent	Sugar beets 2-yr. aver. per cent	Sorghum hay, 1-yr. per cent	Sudan grass hay 1-yr. per cent	Average of the percentages of increase of all crops for six years in per cent
1	Common vetch	25.5	10.4	......	14.0	11.4	......	18.8
2	Non-legume + 123 lbs. N	20.8	24.0	......	19.4	54.3	21.3	24.2
3	Bur clover	26.1	47.4	9.9	29.3	26.4	5.1	25.8
5	Purple vetch	54.3	......	......	......	......	30.4	42.4
6	Non-legume + 41 lbs. N	19.0	3.9	11.8	3.6	11.8	21.7	12.8
7	Vicia ervilia	37.5	39.5	32.2	28.9	8.2	21.9	32.0
9	Canada peas	44.2	46.8	51.0	64.2	27.7	13.5	45.1
10	Non-legume + 163 lbs. N	55.5	32.6	67.9	49.1	52.7	35.9	51.2
11	Tangier peas	56.0	38.5	113.7	66.8	55.4	11.6	58.9
13	Melilotus indica	65.7	53.9	82.0	58.9	47.3	19.1	57.8
14	Non-legume + 82 lbs. N	33.4	24.4	33.3	25.4	31.9	24.9	30.0
15	Fenugreek	34.4	55.0	11.3	32.3	4.0	16.4	30.0
17	Lentils	30.2	24.1	7.8	53.5	22.6	27.0	28.6
Average of legume plots		45.5	39.5	44.0	43.5	25.4	18.1	37.7
Average of nitrogen fertilized non-legume plots		32.2	21.2	37.7	24.4	37.7	24.0	29.6

The use of *Meliotus indica* as a green-manure crop resulted in a gain over adjacent non-legume plots of nearly twenty bushels of shelled corn per acre. This is certainly indicative of the manurial value of this plant. With the other five indicator crops, a marked increase is also noted. Not only did such results follow the use of *Melilotus indica* as a green-manure crop, but to a greater or less extent the same was true following the other legumes.

The fact that different crops were used necessitates the showing of the average increases in percentages rather than in pounds or tons. The column to the extreme right in table 4 gives the average increase of all crops for each of the plots where nitrogen additions have been made either from commercial fertilizers or from the air through the agency of legumes.

The nine legume plots show an average percentage of increase over the non-legume plots of approximately 37 per cent, while a like average of the four cereal plots where nitrogen has been added each year at an average rate of 102 pounds per acre shows only a 30 per cent increase in yield. It is significant that the non-legume plot receiving nitrogen at the rate of 163 pounds per acre, gave for the six years an average increase of 51 per cent, while the plot where *Melilotus indica* was used as a green manure, shows an increase of 57 per cent without the addition of any nitrogenous fertilizer.

SUMMARY

A number of legumes make satisfactory growth when used as winter green manures in southern California. Of these, *Melilotus indica* is the most promising; others of value are common vetch, bur clover, and Canada peas. Fenugreek and lentils cannot be depended upon to give heavy yields and the seed is expensive. Purple vetch, Tangier peas, and bitter vetch (*Vicia ervilia*) possess advantages over most of the other varieties tried, but there is as yet no seed available in commercial quantities. From the standpoint of tonnage alone, rye and barley have both given heavy yields in time for spring plowing.

The incorporation of the legume green manures resulted in much heavier yields of the summer field crops, than followed the non-legume green manures. The average yields of all legume plots when compared with that of the non-legume plots show the following increases in yields from legume green manures; with corn, 45 per cent, or fourteen bushels per acre; with potatoes, 39 per cent, or sixty-two bushels; with cabbage, 44 per cent, or two and a half tons; with beets,

43 per cent, or six tons; and with sorghum and Sudan grass hays, 22 per cent, or one ton dry hay. The average for all crops showed an increase of 37.7 per cent. The cultural cost of growing the field crops were the same in both cases, and if we assume that the yields on the non-legume plots, representing as they do about the state average production, are sufficient to defray the actual producing cost, this gain represents clear profit.

The use of nitrate of soda or dried blood resulted in marked increases in yield when compared with those obtained from the unfertilized non-legume plots. The average increase with all field crops was 30 per cent. This increase was brought about, however, at an average expense of from $30 to $35 per acre. The value of these increases did not cover this expense except in the cases of cabbage and potatoes. This was true whether large or small amounts of nitrogen had been added. With cabbage and potatoes, the high value of the product made the applications of relatively heavy amounts of nitrogenous fertilizer profitable.

B. RESULTS OF GREEN MANURES IN A CITRUS ORCHARD

OBJECT OF EXPERIMENT

Winter-grown green-manure crops are largely used in the citrus orchards of California. The benefits derived from the growth of legume manures in the citrus orchard are brought out by a comparison of four of the twenty-one plots of the fertilizer experiment in the Rubidoux block of the Citrus Experiment Station, Riverside, California. It is the purpose of this discussion to bring out the several measured effects following the continued use of stable manure (Plot F), stable manure and raw phosphate rock (Plot O), and stable manure, raw phosphate rock and legume green manures (Plot U). The unfertilized trees (Plot B) being used as a check.

OUTLINE OF EXPERIMENT

Plots B and F contain six Navel orange trees, six Valencia oranges, six Eureka lemons, and six Lisbon lemons. Plot O contains only four of each variety, while Plot U contains five trees of each of the first three varieties named, but no Lisbon lemons. For this reason, this variety is not considered in the discussion. The plots were so arranged that they may be irrigated separately. The cultural operations were carried on in as uniform a manner as possible, considering the differ-

ential treatments which called for the growth of a winter legume on Plot U. Winter crops of barley were grown and turned under on Plots B, F, and O during the first six years of the experiment.

Table V shows the fertilizers applied during the first ten years of the experiment.

RESULTS

Table VI gives the results of the various treatments as measured in terms of yield, grade, size of fruit, size of tree, and estimated amount of the citrus disease known as "mottled leaf."

Yield.—The most noticeable thing in the entire table is the extremely low yield of the unfertilized Plot B. In fact, many of the trees have not yielded a single fruit for the past two years. Their appearance is characteristic of trees suffering from starvation.

The effect of stable manure on the yield is exceedingly marked in the case of all three varieties. In comparing the yields of Plot O with those of F, it is of especial significance that the differences are not marked, and though favoring O in Navel oranges and lemons, they favor F in Valencia oranges. In fact, when considering these yields as representing the aggregate of six years, the differences cannot be considered as beyond the limits of experimental error. The effect of increasing the phosphorous content of the soil through the application of slag and raw phosphate rock seems at the end of seven years to have had little, if any, effect on the yields of these trees.

Assuming that the yields of F and O are virtually the same, although O received twice as much phosphoric acid, it is not probable that the increase in yield of U over F and O can be in any large part ascribed to the fact that U received three times as much phosphoric acid as F. It is impossible to ascribe the above increase to the manure because the total applied on U during the first ten years was forty-six tons less per acre than that applied on F or O. Neither can these differences be ascribed to the small applications of commercial fertilizer which were made during the first three seasons' growth of the trees, for at the end of five years' growth there was no marked difference between F, O, and U, as regards appearances or size. The increase in yield of Plot U over that of F or O, must be ascribed therefore to the fact that Plot U consistently received green manures. The roots of the legumes were well inoculated and undoubtedly drew upon the supply of nitrogen in the air, for a part of the nitrogen found in their tissues. Again, tonnages of organic material were thus

TABLE V

Annual Fertilizer Applications

Phosphatic fertilizers in pounds per acre. Stable manure in tons per acre.

Plot	Material	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	Ten-year total	Total elements applied N	Total elements applied P_2O_5
B	Unfertilized	......	......	......	......	......	......	......	......	......	......	....	0	0
F	Stable manure	10.8	10.8	10.8	10.8	10.8	10.8	13.6	14.6	14.6	22.7	130.3 tons	1300	946
O	Stable manure	10.8	10.8	10.8	10.8	10.8	10.8	13.6	14.6	14.6	22.7	130.3 tons	1300	1998
	Slag	......	......	......	648	1324	......	......	......	......	......	1972 lbs.		
	Raw phos. rock	......	......	......	......	......	146	561	510	610	421	2348 lbs.		
U	Stable manure	......	......	......	10.8	10.8	10.8	12.9	10.8	10.8	17.3	84.2 tons	841	2828
	Raw phos. rock	......	......	......	......	540	540	864	1296	1620	1620	6480 lbs.		
	Superphosphate	......	......	......	540	......	......	......	......	......	......	540 lbs.		
	Commercial 4-8-4	216	216	216	......	......	......	......	......	......	......	648 lbs.		
	Legume green manures	......	......	......	......	......	......	......	......	......	......	....		

TABLE VI

Plot Averages of the Measured Results from the Several Treatments

Plot	Yields in pounds per tree 1912–1916			Per cent Fancy and choice fruit			Per cent desirable sized fruit (150s–176s–200s)		Per cent tree-ripe	Volume of trees in cubic feet			Percentage of mottled leaves of all varieties		
	Navels	Valencias	Lemons	Navels	Valencias	Lemons	Navels	Valencias	Lemons	Navels	Valencias	Lemons	1913	1914	1915
B	32	33	65	69	67	34	33	26	22	568	662	787	10	25	20
F	163	414	335	72	78	41	33	33	16	869	958	1093	5	30	25
O	180	379	347	65	78	62	30	28	12	675	856	1114	3	8	10
U	451	570	510	71	88	62	47	54	9	1064	1128	1435	1	3	5

produced which in their incorporation with the soil undoubtedly increased its organic content for a time at least. Being green and succulent at time of plowing the material rapidly underwent decomposition, thus performing the functions of so-called "active organic matter," and at the same time liberating large quantities of nitrogen which were temporarily locked up in the tissues of the plant while growing during the winter. Determinations on the nitrogen transformations in these plots have been made by McBeth.[3] These activities going on during the seasons of blooming and of setting fruit may be in large part responsible for the heavier yields obtained from Plot U as compared with F.

Quality

Heavy applications of nitrogenous fertilizers, especially if they be bulky, as in the case of stable manure, have been frequently condemned because of the belief that they tend to produce coarse fruit of a low commercial grade. During the seasons of 1914 and 1915, the fruit from these plots was carefully graded. The results as given in table VI do not support the theory mentioned above, but on the contrary show as large a percentage of high-grade fruit on Plots F, O, and U, as on the check, and with lemons a very marked advantage is evidenced on O and U. This last is largely due to the smaller percentage of lemons that became tree-ripe before reaching full size. The column showing the percentage of tree-ripe lemons on the four plots again points to the general superiority of Plot U as regards quality of fruit. The column devoted to a comparison of the percentages of the desirable sizes, shows an advantage in the case of Plot U as regards size of fruit, i.e., an increase of 17 per cent of desirable sizes in Navel oranges, and 28 per cent in Valencia oranges. Plot F and O do not show marked effects upon size of fruit from their several treatments.

Size of Tree

Vegetative growth is certainly an indication of vigor and health, and with other factors equal, the larger the tree the larger the crop. Since marked differences existed in the size of the trees in the several plots, a method of getting the size of tree by volume was adopted in

[3] McBeth, I. G., Relation of transformation and distribution of the soil nitrogen to the nutrition of citrus trees. Jour. of Agricultural Research, vol. IX, no. 7, pp. 194–195, 1917.

1914. A standard fumigation tent was used and the volume calculated by means of the Woglum[4] formula.

In the columns on tree sizes, there is shown to be a marked increase in size where fertilizers were applied. Trees of all varieties are much larger on Plots F, O, and U, than on B, but between F and O, there is no constant difference. Trees on F are slightly larger than those on O in the case of oranges and smaller in the case of lemons. This fact again emphasizes the relative uniformity of results obtained on these plots regardless of the difference in the amount of phosphate fertilizer applied.

"Mottled Leaf"

Since the plots discussed have been on a relatively uniform type of soil and have been handled as uniformly as the experiment permitted, it is at least interesting to note the marked differences in the percentage of abnormal mottled leaves as shown in the three right-hand columns of table VI. These figures were obtained by taking the averages of several estimates made by a number of separate investigators during the fall months of the three years mentioned.

Trees on Plot U have consistently remained more normal as regards leaf development than on the other plots here considered. At the present writing, B stands as before, giving every evidence of starvation, but not showing any material increase in the percentage of mottled leaves. Plots F and O show some increase in the amount of mottling. This is more pronounced on O than on F, as the two plots are more nearly similar in this regard than formerly. Plot U shows quite a tendency toward further increases in mottling this season. This is not especially marked with the lemons and Navel oranges, but is beginning to be pronounced with the Valencias.

[4] Woglum, R. S., Fumigation of citrus trees. U. S. D. A., Bureau of Entomology, Bul. 90, Pt. I, p. 28.

C. GENERAL DISCUSSION

METHODS OF HANDLING

In handling green-manure crops, too little care has usually been taken to insure a good stand. This is probably due to a general lack of knowledge of the real value of such crops. When the bitter clover crop will duplicate in result applications of dried blood, costing $35 per acre, the question of how to insure success with the clover becomes one of considerable importance.

TIME OF SEEDING

In the citrus grove, it is usually considered wise to plow early; that is, during February or March. A good development of any one of the legumes cannot be expected in less than five months. Thus, it is essential to sow the seed during September or the early part of October. In the case of the annual field crops, such as were grown in this experiment, the green-manure crops can be planted after harvesting of such crops as corn, beets, Sudan grass, and the like. With late corn and cotton, the seed may be sown with the last cultivation and thus get a much earlier development of the legume than would result from awaiting the removal of the crop before seeding.

AMOUNT OF SEED TO SOW

The amount of seed to sow will vary with conditions, such as the variety and the actual percentage of the land planted. In young orchards practically all the land can be planted, while in old orchards frequently less than one-half the land is available. Since this percentage of available land will vary so greatly, it is left to each grower to determine the rate of seedage. Taking all the land into consideration, as in a newly planted orchard, or after annual crops, the following amounts of seed per acre may be recommended:

Crop	Pounds per acre	Average price in cents per pound
Melilotus indica and bur clover	20 — 30	6 — 14
Fenugreek	35 — 40	8 — 12
Vetches	70 — 80	3 — 6
Peas	90 — 100	4 — 6
Windsor beans	100 — 200	3 — 6
Lentils	60 — 70	9 — 11

Methods of Sowing

The preparation of the soil is another important matter. The small seeded species, such as bitter clover, demand a good seed-bed to insure germination. The soil should be thoroughly worked up with cultivator, disk-harrow, or plow, following the irrigation preceding the sowing of the seed. With bitter clover, the method that has worked to the best advantage has been to broadcast one-half the seed on the dry soil mulch before furrowing. The soil should then be lightly harrowed to cover the seed. After furrowing, the other half of the seed should be sown broadcast over the furrowed land. The portion of the seed falling in the furrows will be covered by the sifting down of the soil on the sides of the furrow, when the water is first turned in. In this way, a good stand can be obtained in the furrow, and if the land is wet to the surface between the furrows, a good stand should follow over all the land.

With vetches and peas and all those plants having relatively large seeds, the most successful method has been to irrigate the land and follow as quickly as possible with a cultivator to establish a loose seed-bed. As soon as this is completed, the seed should be sown with a drill to a depth of from two to three inches. Furrowing should follow the drilling in order that no further working of the land be required after the seed has sprouted.

Water Requirements of Manure Crop

The question of irrigation is very important. As a general rule, it may be said that with a rainfall of fifteen inches or less, no green-manure crop should be grown if irrigation water is not available. Even in some of the irrigated districts, the supply of water during the fall months is not sufficient to keep both the cover crop and the trees in good growing condition. Under these conditions, the question of growing a green-manure crop is one of getting more water. However, the great majority of orchards are so situated that during the cool fall and winter months sufficient water is available to keep both crops growing normally.

After the cover crop has germinated, it is important to keep as much of the original stand alive as is possible. From the standpoint of the cover crop, light but frequent irrigations are best. However, with many growers, it is impossible to get water more frequently than once every thirty days. Under this condition, in the interior valleys, it is often wise to wait until the latter part of September or the first

of October to plant, in order to miss the excessive heat so often experienced during September. Since the rains do not usually begin until December, from two to four irrigations of the green-manure crop are ordinarily required.

The distance between the furrows is also an important item in the irrigation of these crops. On the lighter soils, the furrows should be made close together, from eighteen to thirty inches apart; while on the heavier types the distance may be greater and yet permit of the surface becoming wet between the furrows.

Incorporation of Green Manures with the Soil

After having grown the crop, it is all-important to incorporate it properly with the soil, for only by so doing is it possible to get the greatest benefit from its use. Unless the crop is worked into the soil before the rains have ceased, it is highly advisable to turn the crop under deeply. In fact, even when a rain or two follows the turning-under of the crop, only a small part of the plant food can possibly be washed down to the roots, as in this short time only a portion of it can have been broken down and become soluble. That portion of the crop which lies in the cultivated surface soil after the rains have ceased can be of but very little value to the growing crop. With furrow irrigation, it is practically impossible to carry down the soluble fertilizer salts that are in the soil above the level of the water in the bottom of the furrow.[5]

Again, the high temperatures and excessive aeration of the cultivated surface soil are very exhaustive of organic material. The cultivation of the soil at such frequent intervals as is commonly practised does not permit of root development into this surface soil. Thus for a variety of reasons, it seems advisable to turn under manures, whatever be their nature, to a depth somewhat in excess of the depth to which the soil is cultivated (figs. 6 and 7). Thus, if it is necessary to cultivate five or six inches deep in order to conserve water, plowing should be done to a depth of from seven to ten inches, depending upon the character of the soil and amount of surface roots. Experience has apparently shown that the cutting of the last year's surface growth of feeding roots does no serious damage to the tree, at least when quantities of organic material are by this means made available to the new feeders which will very soon occupy the level between the cultivated surface and the bottom of the plow furrow.

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[5] McBeth, I. G., Relation of transformation and distribution of soil nitrogen to the nutrition of citrus trees. Jour. of Agricultural Research, vol. IX, no. 7, p. 251, 1917.

In fact, Plot U, which is shown in table VI to be one of the best plots in the Station orchard, has been consistently plowed ten inches deep each year. A mass of feeding roots have been cut every year, but within sixty days new feeders have largely taken their place. It is still more significant that the first growth in the spring has been

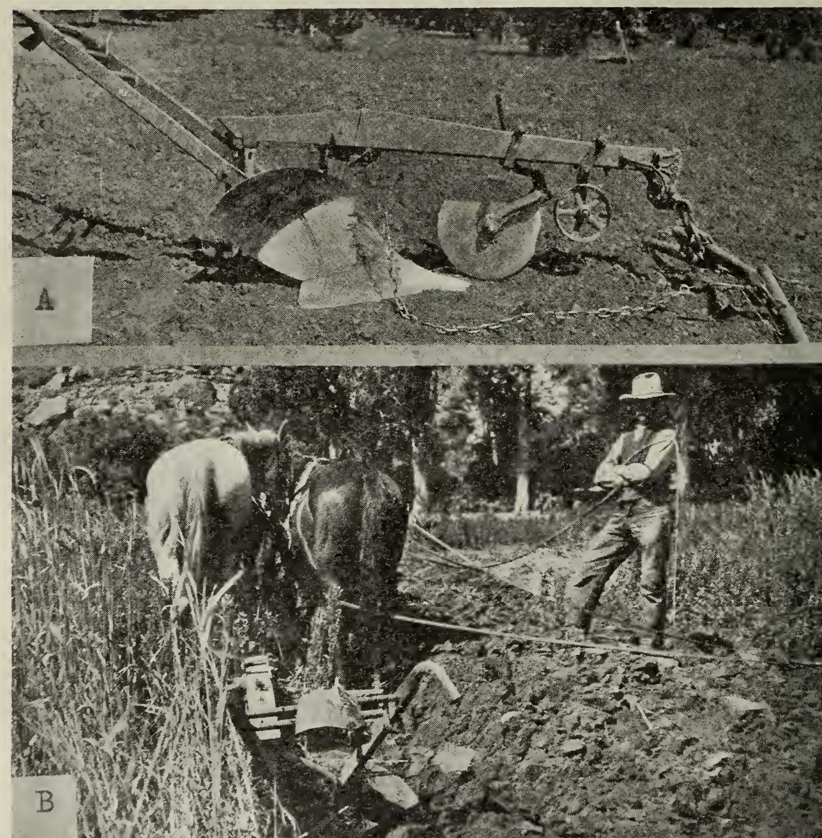

Fig. 6.—A, 18-inch moldboard plow used to turn under heavy green manure crops. Note rolling coulter and weed chain. These permit the plow to cover the material much more completely than would otherwise be possible. B, Showing plow seen in A turning under a green manure crop taller than the horses' backs. Note how completely the tops are buried. The absence of a slick furrow slice or the presence of clods shows this land to be in proper condition for plowing.

noticeably larger-leaved and more vigorous than in the other plots. This seems to indicate that the locating of the manures within easy reach of the feeding roots much more than overcomes the losses due to the root pruning at the time of plowing.

In the case of large plantings and a relatively short period for plowing, a disk-harrow may be used advantageously to cut up the green-manure crop and establish a mulch to prevent the drying out of the soil until the plow can finish the work. At times the anticipated late rains do not materialize. In this case, the land should be irrigated before plowing, since nothing is more exhaustive of time and energy than to attempt to turn under a heavy manure crop after the soil has become dry. In fact, this practice may injure the trees to such an extent as to affect the set of fruit markedly for that season.

The cultivations of the soil following the turning-under of a manure crop should be done with a disk or knife harrow in order that the organic material may not be pulled out on the surface again. Usually in from six to eight weeks, the regular cultivators may be used, although in some soils there seems to be advantages in the disk and knife harrows, solely apart from their ability to operate in a soil full of bulky, organic material.

INOCULATION OF LEGUMES

All legumes have the power of utilizing certain amounts of nitrogen from the air when their roots are infected with certain species of bacteria. These bacteria form colonies at various points along the roots. The enlargements of the roots to accommodate these colonies are commonly called nodules and are familiar to all who have examined the roots of legumes (vetches, and the like) (figs. 1 and 2). Without the colonies of bacteria on the roots, a legume cannot draw upon the supply of nitrogen in the air. It is thus of vital importance to have the legume roots properly inoculated if they are to be used as green manures to add nitrogen from the air. Without the bacteria on the roots, legumes can add no nitrogen to the soil and are no better than barley or rye in this regard.

All of the nine varieties of legumes tested in the experiment just outlined were very well inoculated by organisms native to the soil. In fact, this was the case the first year they were sown on virgin brush land. Artificial inoculations on this soil have shown no apparent increase in number of nodules or in vigor of plants. Observations made over several of the southern counties have in most cases shown the same general condition. The natural flora of the land contains a large variety of legumes, which are well inoculated and which seem to carry the necessary varieties of bacteria to suit all of the legume crops tested.

MINOR ADVANTAGES OF GREEN-MANURE CROPS

The growth of winter green-manure crops may bring about savings totally distinct from those already mentioned. In many sections, the winter rains are spasmodic, coming down at times very heavily. Since many orchards are located on the sloping land of the low foothills, such heavy rains are apt to do much damage in washing away the top soil. Green-manure crops growing during the season of heaviest rainfall, give almost complete protection from such losses.

Fig. 7.—Showing the appearance of the land immediately after plowing seen in figure 6. Note the total absence of organic matter on the surface.

In fact, many growers would not dare to leave their groves in a clean cultivated condition during the winter for this reason alone. In this sense, the green-manure crop becomes a true cover crop protecting the soil from physical losses.

The use of a legume manure crop to increase the nitrogen supply in the soil has already been discussed from the standpoint of the nitrogen additions from the air. There is, however, another factor involved in the maintenance of an ample supply of nitrogen in the root-feeding area of the soil. Nitrogen in the forms available to plants is extremely soluble and thus is very easily carried by water. During nearly every winter, there are one or more very heavy rains

which with the soil already wet from the irrigations may soak down to depths of ten to twenty feet. This water strikes the surface first and the soluble nitrates, frequently very abundant in the upper three to six inches, go into solution and as further rain falls, that which fell first is gradually pushed downward, still carrying the nitrates taken up along the way. Thus the rains wetting the soil very deeply tend to leach out of the surface soil large quantities of available nitrogen. This loss may be very heavy, as evidenced by work carried on by Dr. I. G. McBeth[6] on the movement of nitrates. A green-manure crop growing during the rainy season takes up a very large proportion of the available nitrogen in the soil, and water passing through a soil on which a vigorous crop is growing, finds little soluble plant food to carry to depths beyond the reach of roots. In the incorporation of the green-manure crop, this stored nitrogen is again added to the soil and is rapidly made available to plants through the decomposition which begins immediately if the soil is moist at the time of plowing.

Most of legumes used as green manures are relatively deep-rooting. Roots of *Melilotus indica* have been found to the depth of eight feet in a citrus orchard (figs. 1 and 2). The annual decay of a multitude of these roots undoubtedly has a marked effect on the capacity of the soil to take up water. Under irrigated conditions, many soils develop irrigation hardpan from the sifting downward of the finer particles of soil, and with constant cultivation, winter and summer, this layer may become so compact that air and water will penetrate it with difficulty. The annual growth of green-manure crops tends to lessen this condition, since cultivation as one of the contributing causes is done away with during six months of each year. The decay of the roots of the crop also lessens the effect of the hardpan left over from the previous years.

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6 McBeth, I. G., *loc. cit.*, p. 244.

SUMMARY

A number of legumes gave satisfactory yields when grown as winter green-manure crops. Of these, *Melilotus indica* is the most promising, both from the standpoint of vigor and available supplies of seed. Extensive use shows it to be well adapted to a great variety of conditions. Purple vetch gave very heavy yields and is more rapid in its early development than the *Melilotus indica.* It should be largely planted when seed becomes available in sufficient quantities.

Bur clover did not give as good yields as Melilotus and is of value mainly in sections and under conditions where its early seeding habit will permit of its reseeding itself.

Fenugreek is not well adapted to use in southern California.

Spring vetch (*Vicia sativa*) and Canada peas are of value in certain sections where the green pea aphis is not yet a factor.

Legumes were shown to be far superior to non-legumes as green-manure crops when measured by their effect on field crops following. The yield of a number of crops following legume green manures when compared with those following non-legumes showed the following increases: An average increase with potatoes of 39 per cent; with corn, 45 per cent; with cabbage, 44 per cent; with sugar beets, 43 per cent, and with sorghum and Sudan grass, 25 per cent and 18 per cent respectively. Legumes alone gave as good or better results than non-leguminous green-manure crops plus an annual application of 540 pounds per acre of nitrate of soda.

Green-manure crops have had a marked effect on citrus trees. The trees on the plot where legume green manures have been annually turned under are superior in every way to those similarly fertilized, where no leguminous green manure has been used. Green manuring has resulted in a 30 per cent increase in size of tree. The total yields at the age of ten years were 68 per cent greater on the green-manured plot. Not only was more fruit produced, but the proportion of fancy and choice fruit was larger. Green manuring had a marked effect upon the size of the fruit, there being 63 per cent more of the desirable sizes (150s, 176s and 200s) than on the plots not green-manured. The trees where legume green manures had been used were in much better health, as evidenced by the fact that only 3 per cent of the leaves were "mottled" during the seasons of 1912, 1913 and 1914, while on plots similarly fertilized, where legumes had not been used, the average was 13.5 per cent.

Green manures have additional values in that their growth during the winter months prevents serious washing of the soil during heavy rains.

Large amounts of nitrogen are saved from leaching below the limits of roots by growing winter green-manure crops which utilize the excess nitrogen and hold it until spring when they are plowed under. The decay of the roots of the crop tends to make the soil more open to the access of air and water.

Green-manure crops should be sown during September or October, if satisfactory yields are expected by February or March.

The small-seeded legumes, such as *Melilotus indica* and bur clover, have given good stands when broadcasted before irrigation. Vetches and other large-seeded legumes gave better results when planted with a drill after irrigation and subsequent cultivation, than when broadcasted before irrigation.

Irrigation is usually required to grow satisfactory tonnages of the legume green manure crops. When planted in September or October, from three to six acre-inches of water are required to carry the crop until rains begin. With late sowings, rains may sometimes be depended upon to start the crop, but in this case irrigation is usually required to carry the crop to full development in the spring and to enable the crop to be properly incorporated in the soil.

Green-manure crops may be expected to give most satisfactory results when plowed under to a depth of from seven to ten inches. They should never be plowed under when the land is dry, as this will result in poor incorporation of the green tops and slow decay. With field crops, moist plowing is an absolute necessity if a proper seed-bed is to be obtained before planting the summer crop.

Artificial inoculation is seldom necessary in southern California orchards with the winter-growing legumes in common use.

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